PROHITECH – WP2 (Leader G. Altay)

DAMAGE ASSESSMENT:

Some Comments on Seismicity in Israel, Performance Assessment & Damage to Historic Monuments in Jerusalem

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.

A. INTRODUCTION

Buildings in Israel are mostly reinforced concrete: shear walls and/or bearing core, with or without frames, with infill masonry walls, commonly concrete or expanded foam-concrete blocks and increasingly curtain walls, steel-glass or precast sandwich concrete panels. Older buildings are mainly stone masonry or poor concrete bearing walls. Industrial and office building floors are mostly precast prestressed. Light roofs of industrial buildings are usually supported on steel beams and trusses. The use of steel in multistory structures is limited.

Catalogues of earthquakes (EQs) affecting the area list many destructive pre-historic and historic EQs with M_L magnitudes estimated from 6.3 to 8 (Ben Menahem 1979, 1991, Amiran et al, 1994). Figure 1 shows the epicenters of major earthquakes $M_L > 7.4$ since 2100 BC (Ben-Menahem 1991). A list of events with $M_L > 5.3$ as of 1900 downloaded from the Seismological Institute of Israel internet site is given in Fig.2, together with their epicenter map. From this list it can be seen that two notable events occurred during this period: the 1927 and the 1995 EQs. In fact, the 1995 EQ had only a minor destructive effect on the country as the epicenter was located circa 80 km south of Eilat (at the tip of the Aqaba gulf). Some information on the 1927 event will be given in Sections E and F.

The seismic design of buildings is governed by SI 413 (1995): and Amendment Sheets 1 and 2 thereto from 1998 and 2004 respectively. The 1995 code replaces the 1975 version, and its 4 Amendment Sheets. The latter code superseded a 1961 code proposal, which was based on an earlier Los Angeles code. In those early days designers for several public authorities were also using the extant French code. Codes for non-building structures and systems are now being prepared by the Standards Institution of Israel. Guidelines for seismic resistance assessment and for strengthening of existing structures (SI 2413 2003) are also available of No standard procedures for post-earthquake evaluation are known to the authors

B. QUICK INSPECTION METHODS: *for performance assessment*

The only damaging earthquake in Israel since the beginning of the 20th century was the July 11, 1927 one. Hence it is not surprising that no damage assessment procedures based on local experience are available.

Several screening methods for existing buildings have been developed worldwide during the last twenty years. Following the practice adopted in many countries SI 2413 provides guidelines for three steps or levels of inspection procedures. The first two can be considered as quick inspection methods, and are described briefly in this Section. The third procedure is a detailed one, and forms the subject matter of Section C.

Level I inspection: This procedure is intended for statistical purposes only, i.e. the purpose is to aid decisions regarding expected vulnerability of a city quarter or neighborhood. Its use for actual capacity evaluation of buildings is not recommended. The procedure consists of summation of factors that can be estimated from external visual inspection, without actually entering the premises. This technique is based on the Study Group on Earthquake Risk Buildings Report (1996) in New Zealand, with adjustments to Israeli building practice. After choosing the structural type/category of the building in question (e.g., masonry wall building) in Table 1 of SI 2413, the factor S_0 for the expected PGA at the site per SI 413 seismic map (Fig. 3) is obtained. Several other factors ΔS are added to S_0 (e.g. general state of building, irregularity, pounding, short columns, date of construction and proximity to active faults. The evaluation index I_r is given by:

$$I_r = 1 / (S_0 + \Sigma\Delta S).$$

Value of I_r smaller than 1.0 indicate that the seismic resistance of the building is not satisfactory.

Level II inspection (First Screening): This evaluation procedure is based information obtained from data collected from historical earthquakes in Japan. It gives several simple formulas for the evaluation of seismic capacity, without recourse to seismic analysis. Answers to a questionnaire lead to the "seismic index" of the building.

$$I_s = F_{AT}/ F_T$$

F_T = seismic capacity of the inspected floor, for which simple evaluation formula s are presented, F_{AT} = the seismic force above the inspected floor as obtained for other sets of formula, assuming a linear lateral force distribution along the building height. For $I_s < 1.3$, analysis per SI 413 is required. The basic criterion for the formulas and parameters in Level II is closeness to the requirements of SI 413 (Scarlat ,2004).

Note that the approach is force based, not displacement based.

C. DETAILED INSPECTION METHODS: *for performance assessment*

Level III inspection: SI 2413 requires that when $I_s > 1.3$ assessment be made per the provision of the seismic Code SI 413, and the additional provision in SI 2413. These consist of lowering the force demand on the structure by a factor dependent on the remaining life of the building (e.g. for buildings constructed prior to 1960 the reduction is 33.3%, and for those built from 1975 the force reduction is only 20%). Capacity reduction factors dependent on extent of detailing data are given. The actual state of the structure, the presence of short columns and possibility of pounding has to be taken into account. Additional data are given for masonry buildings and unreinforced concrete walls.

Again, SI 413 was written in the early 1990's, hence it is force-based rather than displacement-based document.

D. COMMON DAMAGE PATTERNS

The only destructive earthquake affecting the country since 1900 was the so called Jericho earthquake of 1927. At that time the country was thinly populated, and most of the buildings were of the traditional stone or block masonry types. Also, available damage reports by professional engineers and seismologists are limited in number; hence not much useful information can be gleaned from that earthquake about damage patterns of modern buildings. The available reports concentrate on traditional stone masonry buildings. Interestingly, a Public Works Department inspector observed that most of the damage in the 1927 EQ was to domed buildings caused by outward pressure at the base. A detailed report on the damage to the cupola of the Church of the Holy Sepulcher is available, and will be referred to again in Section F. The same inspector also noted that the majority of the damaged buildings were of poor construction. Engineered buildings remained in good state after the EQ.

As already noted, minor damage resulted from the Gulf of Aqaba November 1995 EQ, concentrating in the hotel area of Eilat. One notable damage was to the Ganei Shulamit hotel – a poorly constructed reinforced concrete building, which was condemned and demolished, and cracking of concrete elements in other buildings, including one case of severe shear cracking in a short column.

E. DAMAGE STATISTICS

The epicenter of the M_s = 6.25 1927 earthquake was originally located near the Damia Jordan River bridge. In the 1990's this location was disputed (Shapira et al 1993) and is now believed to be circa 40km to the south. An intensity map for that event is given in Fig.4. The damage was extensive. Between 250 and 500 people perished, many of them in Nablus (estimated PGA $\cong$ 0.26g), where the death toll was 60-110. The number of injured was estimated at 400-700. The total number of damaged buildings was estimated at 1000. Damage in Jerusalem (circa 25-30 km from the Dead Sea Fault), with estimated PGA $\cong$ 0.78g-0.87g was extensive – 250 houses were condemned and demolished only in the Old City (see also Section F) although the number of casualties was relatively small (25 dead and 38 wounded). Ground settlements were reported also at a large distance from the epicenter (e.g., at Reina near Nazareth). The Jordan River was reportedly blocked for about 20 hours by a landslide, and a 1.0m high seiche was observed in the Dead Sea. Site effects caused extensive damage in Lod and Ramleh, located relatively far from the epicenter; nearly 500 buildings were apparently completely ruined in the former town. The extensive damage on the Mount of Olives and Mount Scopus near Jerusalem (Hebrew University Campus, Government House, Church of the Ascension, Augusta Victoria hospital) was attributed to site amplification.

F. HISTORIC MONUMENTAL ARCHITECTUTE

Jerusalem is a sacred city to the three monotheistic religions. The most important historic monumental buildings are the al Aqsa mosque, the Church of the Holy Sepulchre and the Dome of the Rock.

The peak ground acceleration expected in Jerusalem, and hence for these buildings per SI 413 (on the basis of 475 years return period) is 0.13g. Although higher accelerations during historical earthquakes have been inferred by experts, Shalem (1949) claims that, with some very unique exceptions, Jerusalem has practically never experienced really destructive earthquakes, and that the extensive documentation relating to historical events is due to the

interest in the city as a very sacred place for the three religions, rather than the severity of the event.

The al Aqsa and the Dome of the Rock are both located on Temple Mount (Haram-a-Sharif) (Fig. 5), which is an almost horizontal platform, raised above most of the surrounding terrain to a level about 4 metres below the famous rock outcrop (the Drinking Stone) near the center, with stone retaining walls along most of its sides supporting the backfill and the buildings above. The Wailing Wall is a section of the western wall, as indeed it is so called in Hebrew. Temple Mount and its huge walls as they are now date from the times of Herod the Great, although much of the leveling and fill was carried out much earlier.

The al Aqsa, the third most sacred mosque in the Muslim religion (after Mecca and Medina), was constructed at the southern side of Temple Mount (Fig. 5) at the end of the 7th and early 8th century. It is a traditional stone masonry building (Fig. 6). Damaged in the 710 and 713/14(?) EQs, and destroyed in the 749 (746 -748?) EQ, it was rebuilt in 758. It was again damaged due to poor construction and/or EQs in 771 and 774, and then rebuilt on a new plan in 780. It was again damaged in 859, 1033, following which extensive rebuilding took place in 1035, including the cupola that still stand to this day. In 1060 the roof of al Aqsa collapsed. The Crusaders who occupied Jerusalem in 1099 turned it into a royal palace, and part of it was given to the Templars. During that period some internal changes took place and several wings were added. No EQ damage to the al Aqsa was reported until 1927. However, the British, who occupied Palestine in 1917, found the mosque, and also other building in Temple Mount, in a state of total neglect and on the verge of collapse. Restoration work started in 1924 most probably saved the building from total collapse in the 1927 EQ. The damage from the 1927 event was extensive (Fig. 7), and necessitated the continuation of the restoration. Following a minor EQ in 1937 extensive restoration took place during 1938-1942, involving demolition of the eastern longitudinal walls and arcades. Old columns were replaced by new marble ones imported from Italy. Following arson in 1969, the mosque was severely damaged, and restoration work was completed only in the mid 1990's. Stabilization of the mosque's foundations by massive concreting in the underground voids adjacent to the Ancient al Aqsa (or the Double Gate) - located under the mosque - was carried out in the 1970's, and its extensive excavations and restoration of took place in the 1990's. A detailed description of the mosque can be found in Hamilton's monograph (1949).

Since the mosque is partly founded on the vaulted Ancient al Aqsa and on rubble, it is probably more seismically vulnerable than the Dome of the Rock, founded on rock, as it name suggests.

The church of the Holy Sepulchre (Fig. 8), built by the Emperor Constantine between 326 and 335 on the ruins of a Roman temple, was destroyed, rebuilt and extended several times during its long history (e.g., Schiller, 1985). Most of the destruction resulted from the animosity between Christians and Muslims, but earthquake had also their share. The Persian conquered Jerusalem in 614 and burned the church. After the recapture of Jerusalem by the Christians in 628 the Church was restored. The Muslim rule of Jerusalem began at 638 after the surrender of the Patriarch to Caliph Omar. It was claimed that the church was damaged by an EQ in 774, but this is doubtful. Damage to the Rotunda from the 808 EQ led to restoration (cedar beams imported from Cyprus). The doors and the conical cupola of the Rotunda were later burnt down. The church was again destroyed in 1009 by the Egyptian Caliph al-Hakim. Restoration work started after the peace treaty between the Moslems and Byzantium, was interrupted by the 1033/34 earthquake swarm, and completed, apparently with additional arcades, in 1048. Following their conquest of Jerusalem in 1099 the Crusaders embarked upon a lengthy

renovation and extension project which was completed only 50 years later. The general layout of the church remains practically the same to this day. Since the recapture of Jerusalem by Saladin in 1187 keys to the church were held by a Muslim family. The upper part of the bell tower was destroyed during the 1545 EQ, and the cupola collapsed in the1546 M_L = 7 EQ (apparently two separate events). Extensive restoration work, including replacement of the Rotunda's cupola was completed in 1719. The 1808 fire caused serious damage to the dome and vaults of the Catholicon. The hasty restoration completed in 1810 included the replacement of the conical roof of the Rotunda by a simple circular cupola, but apparently did not appreciably improve the stability of the building. Following the 1927 M_L = 6.25 EQ the church was no longer considered safe and parts of it, mainly the Rotunda, were supported by metal scaffolding. Some minor damage was added in the 1937 EQ. It remained in this sorry state until the 1960's, when restoration work permitted the removal of the steel bracing. The dome above the Rotunda was fully renovated in 1997.

The 1927 EQ is the first event in Palestine for which detailed engineering damage survey was conducted. The report focuses in the stone dome of the Catholicon and its supporting drum. It notes that the top of dome is very little out of line. However, vertical joints opened in lower 4 metres due to malfunctioning of the iron hoops. It was recommended that the dome be taken down. Static analysis reasoning was provided to support this conclusion.

After the conquest of Jerusalem in 638 the Muslims embraced the sanctity of Temple Mount, and built the original al Aqsa mosque and the Dome of the Rock (Fig. 9), both at the late 7th and early 8th century. The octagonal building dates from the early 9th century. It is covered by two practically independent wooden domes: an external one of an elliptical shape recently covered by gilded copper sheets, and internal one of circular shape, with circa one metre space between the two to allow inspection and maintenance. Whereas the present ornamented internal dome dates from the early 11th century, the external one, built to protect the former, is recent. After the reoccupation of Jerusalem by the Arabs in 1187 the dome was refurbished. The building is considered to be an architectural gem by most experts.

The structure was severely damaged by the 749 (746-748?) EQ. Renovation started in the 780's and apparently completed by Mamoun in 813. Some damage to the dome, or just the fall of its candelabra, was reported following the 1060 EQ. The dome was damaged again in 1068. The 1546 M_L = 7 EQ caused the collapse of the dome. As already noted, the British found the Dome of the Rock in a state of neglect, and restoration work started in 1924. It is difficult to estimate the effect of the 1927 EQ on the building. One press report stated that "…the Dome of the Rock was badly shaken and many repairs of recent years were made useless".

H. Acknowledgements

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Fig. 3. SI 413 seismic map (2004).

Fig. 4. The 1927 EQ isoseismic map (Avni 1999).

Fig. 5. Map of Temple Mount (Seligman & Avni 2001).

Fig. 6. Plan and sections of al Aqsa Mosque (Schiller 1978).

Fig. 7. Damage to al Aqsa in the 1927 EQ (Seligman & Avni 2001)

Fig. 8. Plan and section of the church of the Holy Sepulcher (Schiller 1985a).

Fig. 9. Plan and Section of the Dome of the Rock (Schiller 1985b).

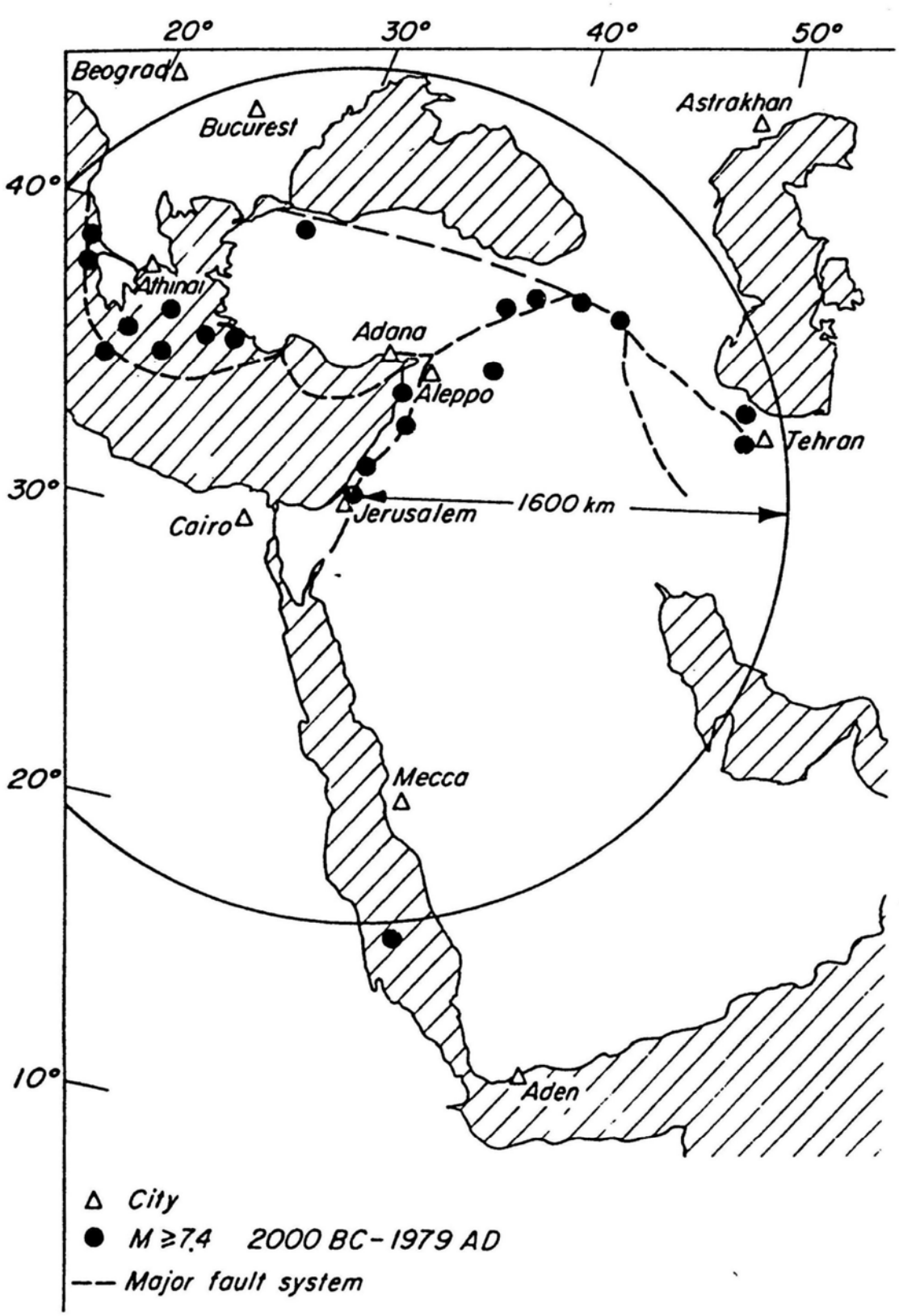


Figure 1. Epicenters of EQs, M_L> 7.4, felt in Jerusalem since 2100 BC (Ben-Menahem 1991).

List of Earthquakes In and Around Israel (1900-2004)

ID	Date	Origin Time	Lat	Long	X	Y	Km	ML	Mb	Mm	MSK	Type	Region
1.	1999-08-11	04:27:58	34.62	33.01	-31.9	450.1	25	5.5	5.4	5	3	F	Cyprus
2.	1999-05-25	17:15:26	34.42	32.37	-90.6	428.7	9	5.3	5.2	4.8	3	F	East Mediter.
3.	1997-05-10	23:01:43	27.97	34.72	123.6	-290	3	5.3	5.1	0	0		Tyran
4.	1997-03-26	04:22:51	33.86	35.39	185.2	363	5	5.5	5.3	5.1	3	F	Beirut
5.	1997-01-13	10:19:25	34.26	32.46	-82.8	411.1	10	5.9	5.6	5.8	3	F	East Mediter.
6.	1996-12-20	07:21:21	27.8	33.15	-29.3	-306.7	25	5.3	5.2	0	0		Arab Desert
7.	1996-10-21	06:00:52	34.29	32.35	-92.5	414.9	25	5.3	5.2	0	0		East Mediter.
8.	1996-10-09	13:10:52	34.4	32.29	-97.9	426.6	7	6.1	5.8	0	4	F	East Mediter.
9.	1996-02-26	07:17:09	28.87	34.63	115.2	-190	17	5.6	5.4	0	3	F	Gulf of Eilat
10.	1996-02-21	04:59:53	28.87	34.67	118.8	-189.8	16	5.3	5.2	0	3	F	Gulf of Eilat
11.	1995-12-11	01:32:03	28.56	34.79	131	-225	11	5.4	5.2	0	3	F	Gulf of Eilat
12.	1995-11-24	16:43:42	28.67	34.96	147	-212.9	10	5.3	5.1	0	5	F	Gulf of Eilat
13.	1995-11-23	18:07:13	28.85	34.91	142.5	-192.3	10	5.4	5.2	0	3	F	Gulf of Eilat
14.	1995-11-22	22:16:55	28.53	34.73	125.3	-227.5	10	5.5	5.3	0	3	F	Gulf of Eilat
15.	1995-11-22	12:47:03	28.45	34.83	134.4	-236.7	5	5.4	5.2	0	3	F	Gulf of Eilat
16.	1995-11-22	04:15:12	28.76	34.68	120.2	-202.2	14	6.2	5.9	0	6	F	Gulf of Eilat
17.	1993-11-03	18:39:25	27.98	34.88	139.5	-288.5	16	5.3	5.2	4.3	2	F	Tyran
18.	1993-08-03	16:33:22	28.8	34.82	133.9	-198.6	4	5.6	5.4	0	3	F	Gulf of Eilat
19.	1993-08-03	12:43:08	28.45	34.82	133.8	-236.9	13	5.8	5.6	5.1	4	F	Gulf of Eilat
20.	1989-03-31	00:44:14	31.88	37.46	380.4	144.3	12	5.4	5.3	0	4	F	Wadi Sirhan
21.	1984-08-24	06:02:25	32.66	35.18	166.3	229.4	18	5.3	5	0	0	FS	Galilee
22.	1983-06-12	12:00:13	28.89	32.96	-45.1	-185	27	5.4	5.1	0	0	FE	Abu Rodes
23.	1983-02-03	23:30:25	29.22	34.77	128.9	-151	2	5.3	5.1	0	4	F	Gulf of Eilat
24.	1972-06-28	09:49:35	27.7	33.8	32	-319.6	0	5.3	5.5	0	0		
25.	1969-03-31	07:15:54	27.61	33.91	42.9	-329.6	33	5.9	6.1	0	0		
26.	1961-09-15	01:46:0	34.98	33.87	47	488	10	6	5.9	0	0		Cyprus
27.	1959-06-13	12:01:0	34.82	32.86	-45	472	10	5.5	5.4	0	0		Cyprus
28.	1957-11-03	09:56:0	32.5	35.92	235	212	10	5.5	5.4	0	0		Kineret
29.	1956-12-18	17:53:0	31.47	35.49	196	97	10	5.5	5.4	0	0		Arad
30.	1956-03-16	19:43:28	33.3	35.3	179	306	10	5.5	5.5	0	0		
31.	1956-03-16	19:32:0	33.35	35.32	179	306	10	6	5.9	0	0		Tyre
32.	1953-09-10	04:06:0	34.67	32.29	-97	457	10	6.2	6.1	0	0		Cyprus
33.	1952-10-15	17:50:0	34.78	32.8	-51	468	10	5.6	5.5	0	0		Cyprus
34.	1951-01-30	23:07:0	32.26	33.36	-3	187	80	5.8	6.2	0	0		East Mediter.
35.	1941-01-20	03:37:0	35.18	33.65	27	511	10	6	5.9	0	0		Cyprus
36.	1940-07-24	22:15:0	34.56	34.15	72	441	10	5.7	5.6	0	0		Cyprus
37.	1927-07-11	13:04:06	31.6	35.4	190	110	10	6.2	6.1	0	0		Amman
38.	1924-02-18	17:04:0	34.42	33.95	53	426	10	6	5.9	0	0		East Mediter.
39.	1922-04-02	00:47:0	34.73	34.8	131	459	10	5.5	5.4	0	0		East Mediter.
40.	1918-09-29	12:07:0	35.24	36.11	249	516	10	6.5	6.4	0	0		Hamma
41.	1900-01-05	00:00:00	35.2	33.2	-13	513.1	0	6.2	6.3		0		Cyprus

Origin Time is in Universal time (GMT)

Lat,Long - Geographic coordinate.
x,y - Israel coordinate.

Km - Focal depth in Km

ML Local Magnitude, **Mb** - Body wave magnitude
Mm (estimated), - Moment magnitude (using SP)

MSK - Maximum observed Seismic intensity in Israel (MSK scale)

Type - PE - Possibly an explosion, F - Felt, FS- Felt strongly

Highlighted epicenters indicate that there is additional information (Fault Plane Solutions and/or Descriptions of the effects and/or pictures).

Figure 2: List of EQs and epicenters, $M_L > 5.3$ since1900, (**www.gii.co.il**).

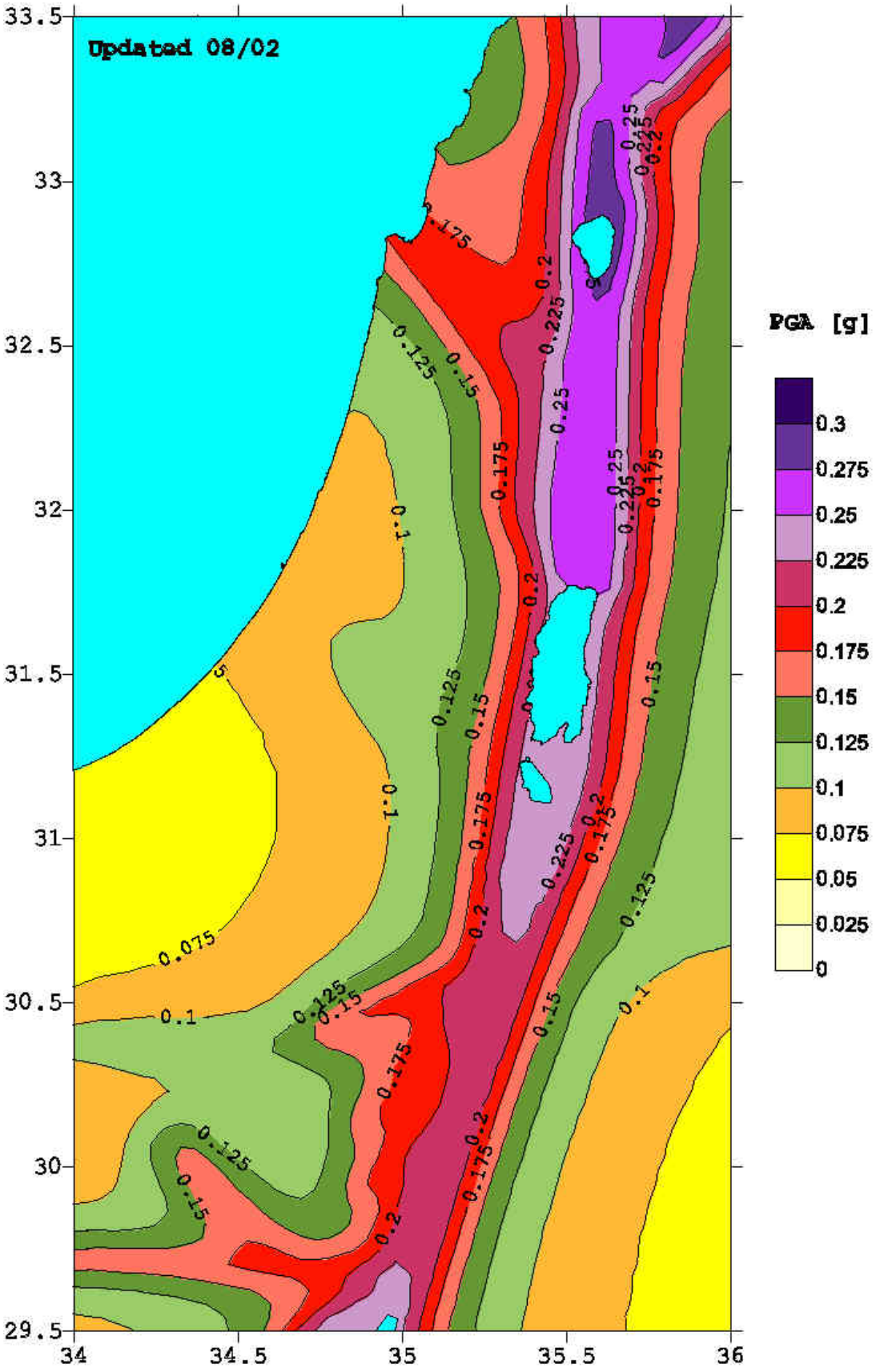


Figure 3: SI 413 seismic map (2004).

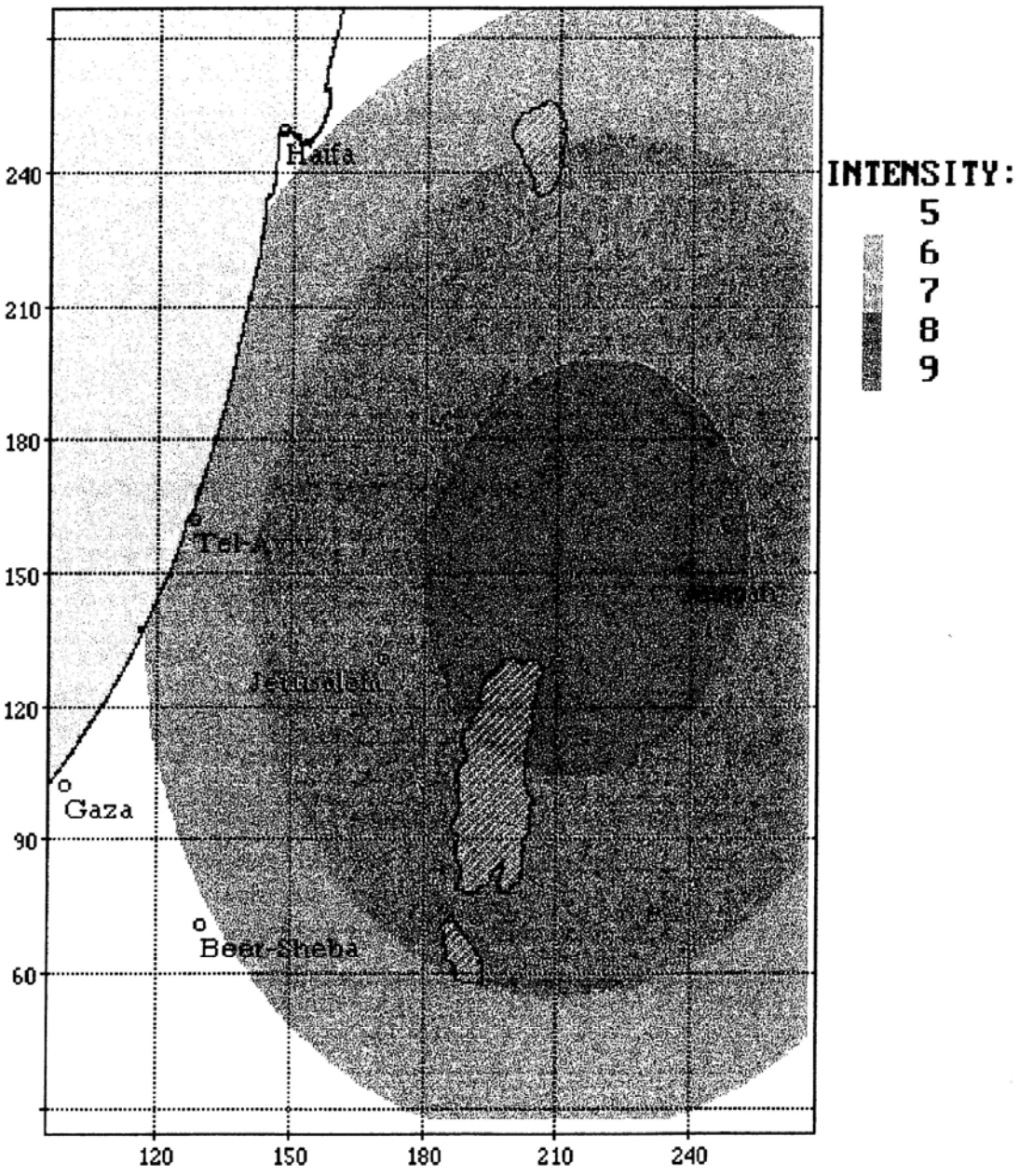


Figure 4: The 1927 EQ isoseismic map (Avni 1999).

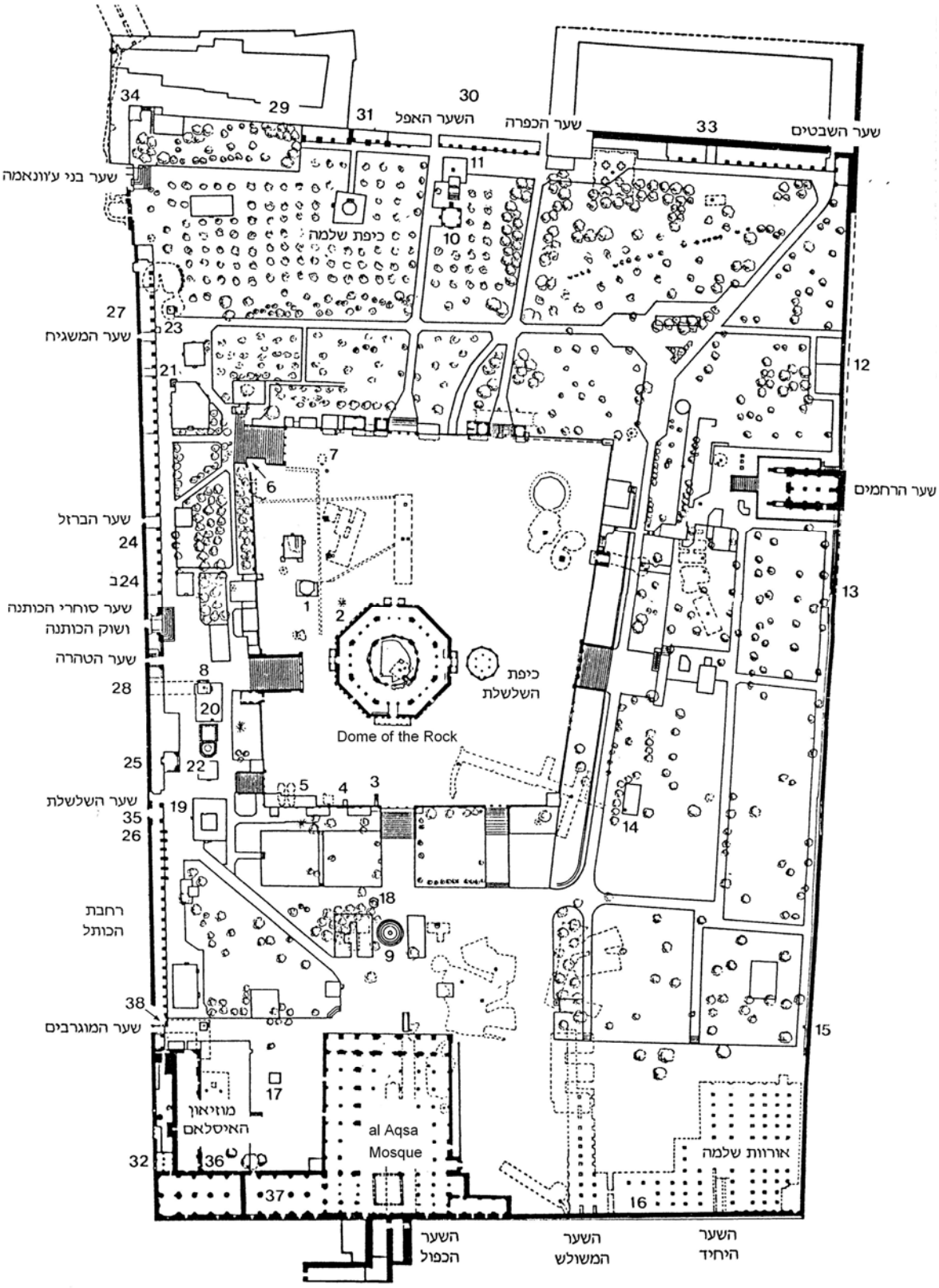


Figure 5: Map of Temple Mount (Seligman & Avni 2001).

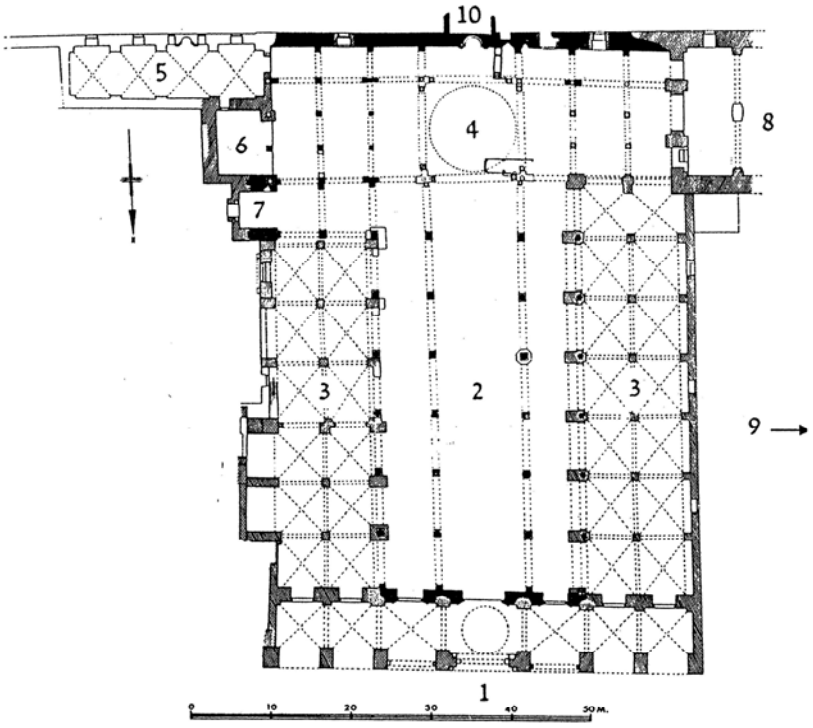


Figure 6a: Plan of al Aqsa Mosque (Schiller 1978).

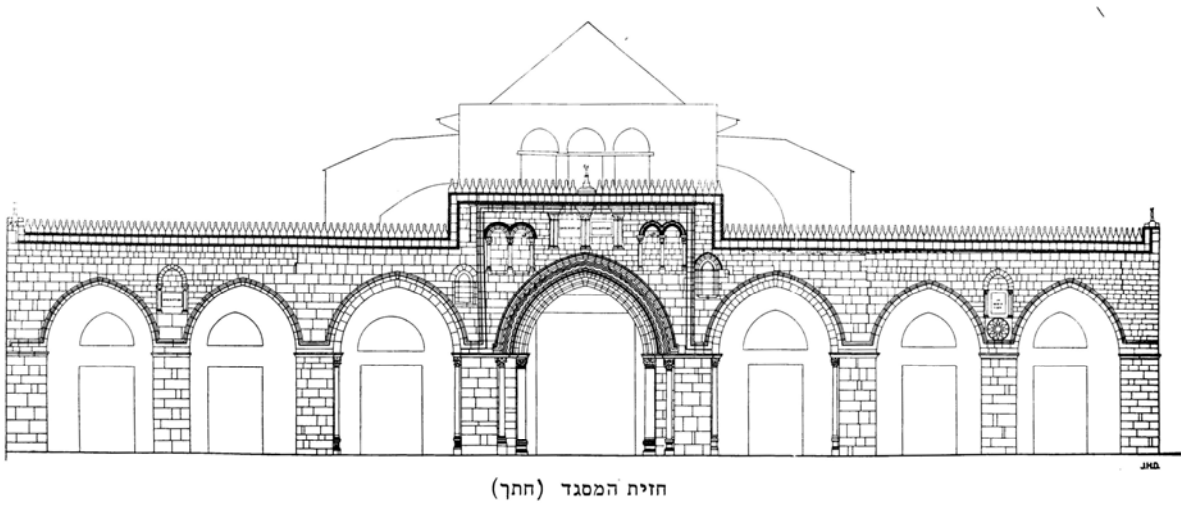


Figure 6b: North Facade of al Aqsa Mosque (Schiller 1978).

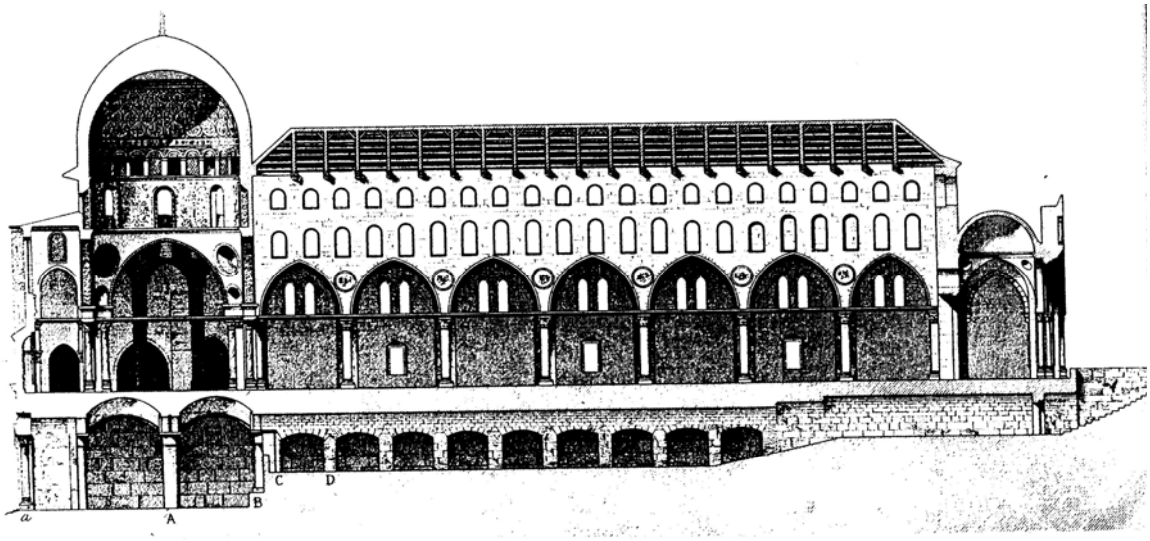
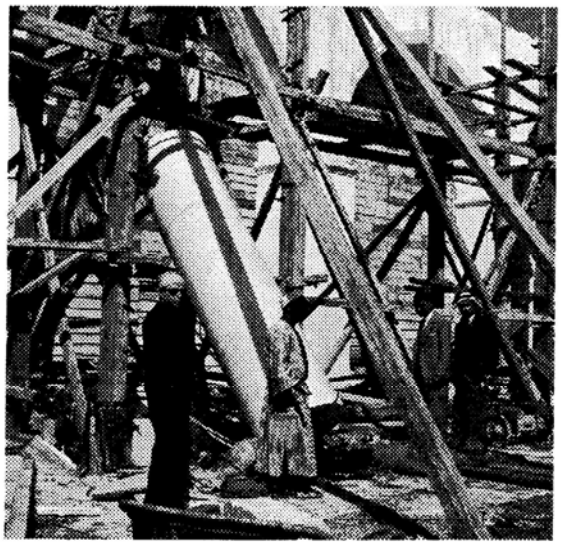
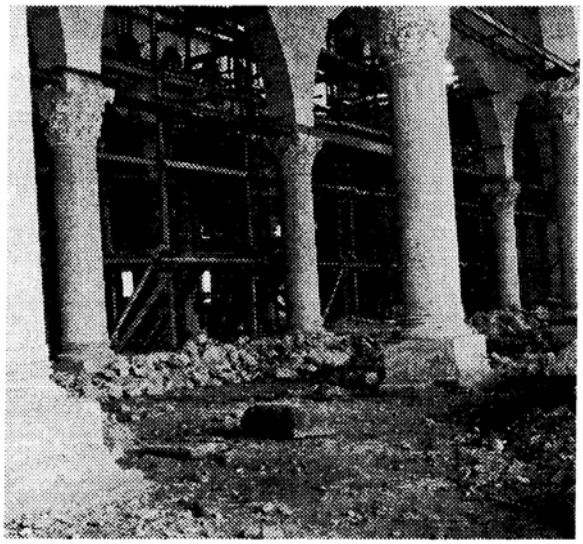


Figure 6c: N-S Section of al Aqsa Mosque (Schiller 1978).



תצלום 7. מסגד אל־אקצא : עבודות שיקום — הצבת עמוד חדש, מבין העמודים שיובאו מאיטליה.



תצלום 8. מסגד אל־אקצא : עבודות שיקום.

תצלום 9. מסגד אל־אקצא : עבודות שיקום.

Figure 7: Damage to al Aqsa in the 1927 EQ and restoration work(Seligman & Avni 2001)

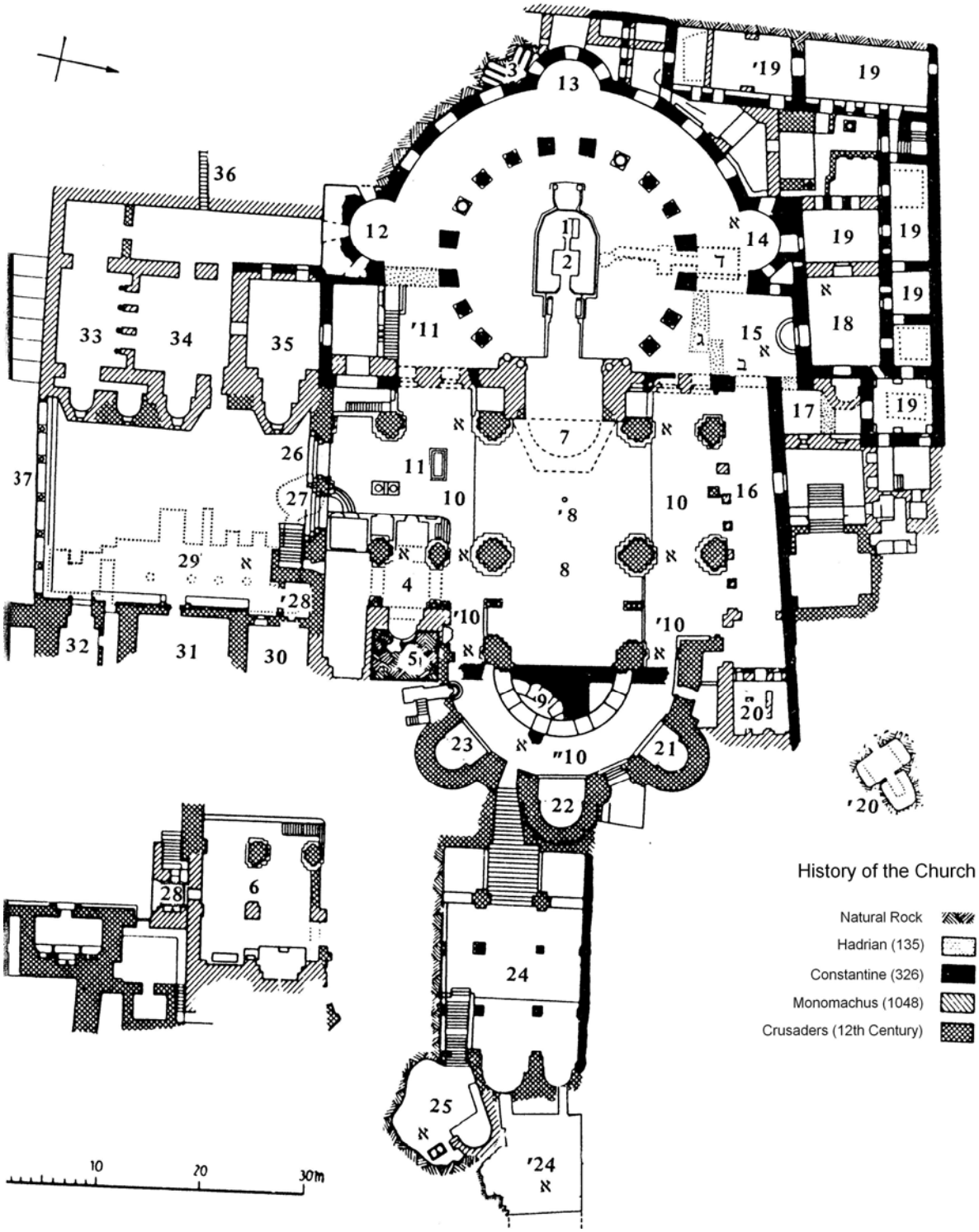


Figure 8a: Plan and section of the church of the Holy Sepulchre (Schiller 1985a).
(1 – Holy Sepelchre; 2 – Angle's Chapel; 8 – The Catholicon; 8' – Center of the Universe)

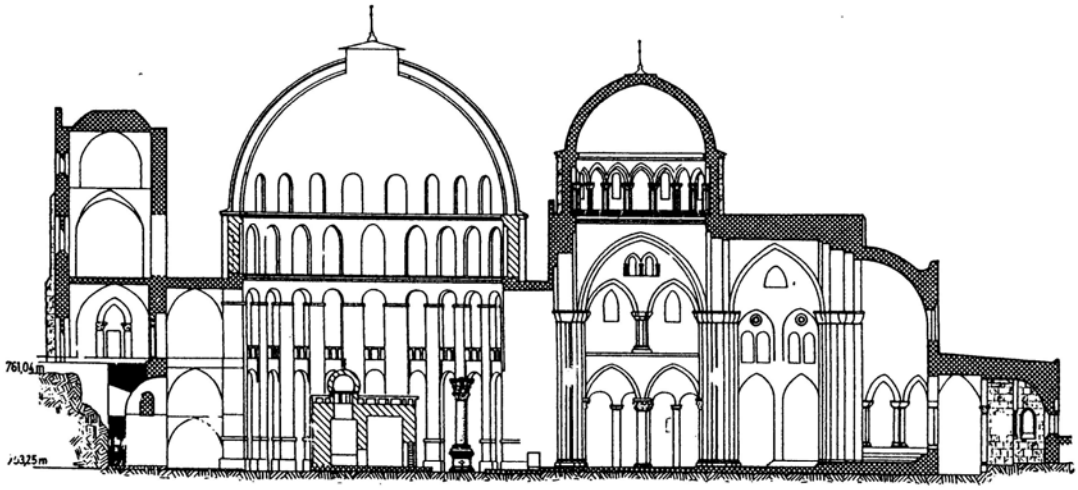


Figure 8b: Section of the church of the Holy Sepulcher (Schiller 1985a).

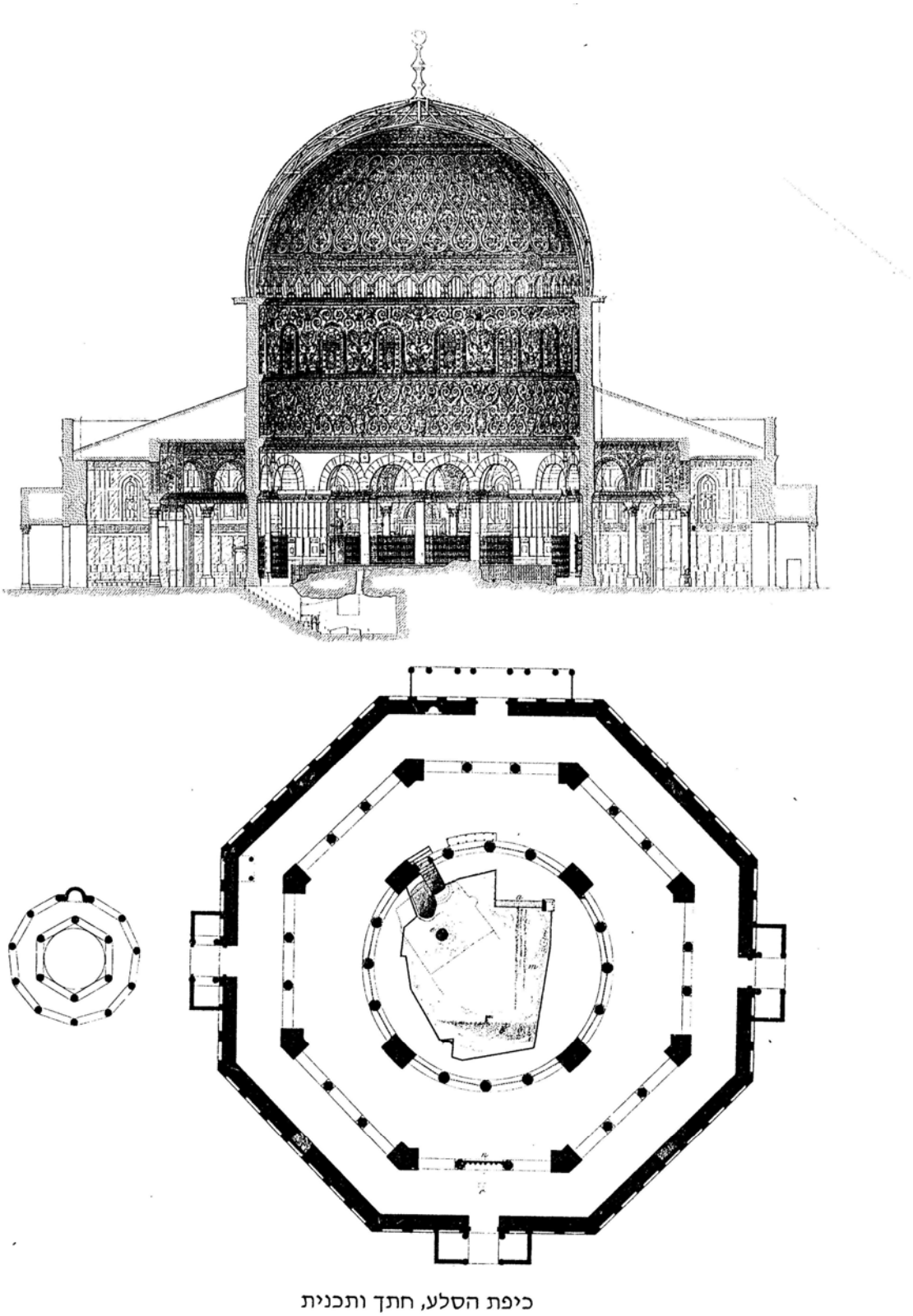


Figure 9: Plan and Section of the Dome of the Rock (Schiller 1985b).

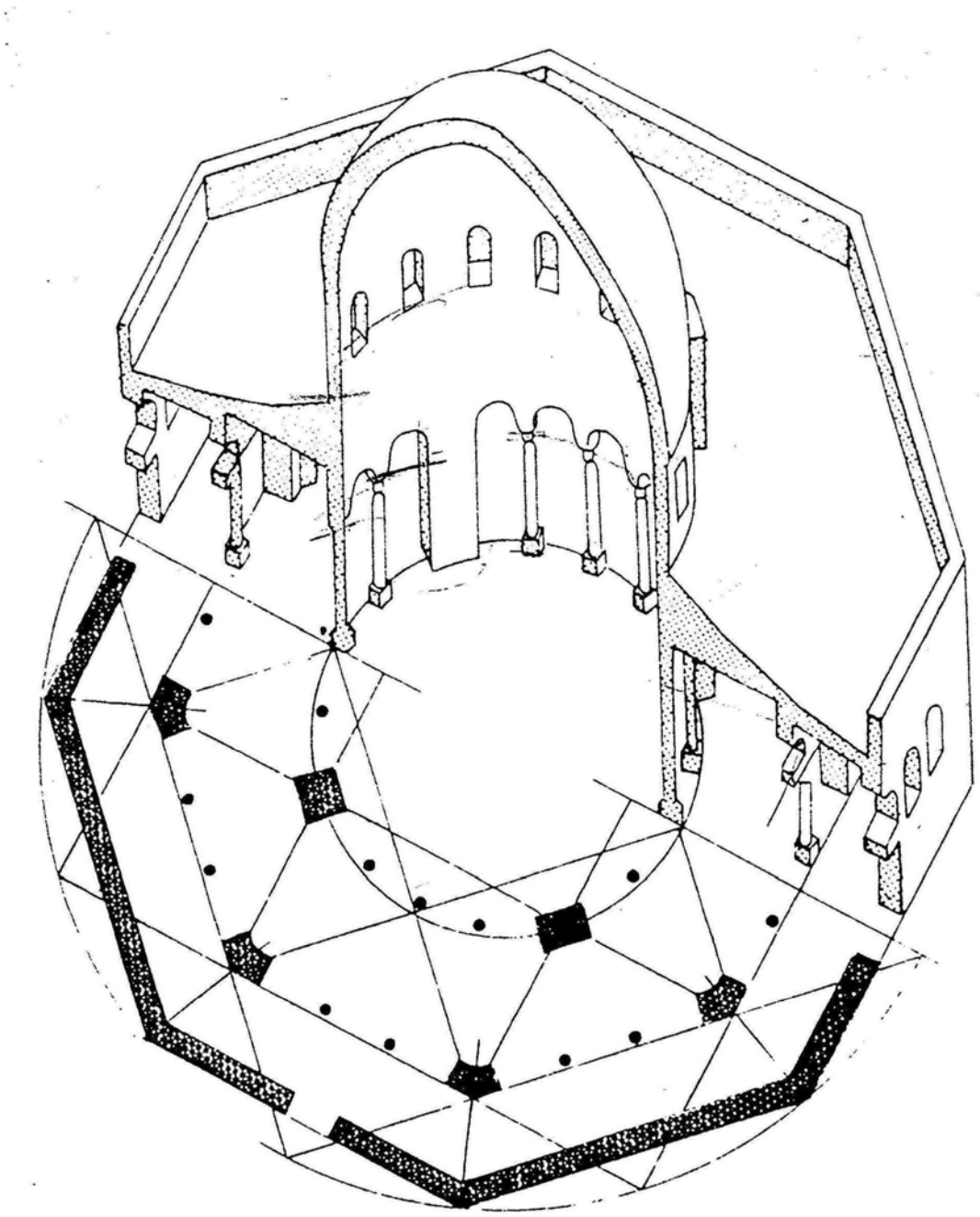


Figure 9b: View of the Dome of the Rock (Schiller 1985b).